

A RADAR VARIANT FOR A METEORIC WIND PATROL

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ABSTRACT. The development of the SOM-III radar is described.

References [1-5] have reviewed the basic requirements for radar designed to investigate the physics of a meteor trail, and to study the physical characteristics of the upper atmosphere.

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The parameters of a radar with a master oscillator, as well as with a self-excited oscillator, had been discussed previously, and had been included in the decisions made by the Commission of the Interdepartmental Geophysical Committee of the Presidium of the Academy of Sciences of the USSR in April-June 1962.

The recommended principal characteristics of radars were: wavelengths $\lambda = 8$ m; pulse power $P_p = 100$ kW; pulse width $\tau \geq 10$ μ sec; repetition frequency $F_r \geq 200$ pps; antennas with a gain of $G \approx 15-20$; receiver with an optimum bandwidth $\Delta f = 1/\tau$ and response $\alpha \approx 10^{-13} - 10^{-14}$ W.

The authors adhered to these basic requirements during the development of complex measuring equipment, the result of which was the SOM-III radar. This paper is devoted to the justification and selection of the block diagram for a meteoric wind patrol radar.

The SOM-III radar was developed to study the density of meteor material radiant points in the celestial hemisphere and atmospheric circulation.

The selection and development of the block diagram for a radar to record the following parameters of a meteor echo proceeded from a concretely formulated task that included:

- (a) frequency and time of appearance of the echo;
- (b) meteor echo range determination;
- (c) measurement of angles of arrival from a reflecting point by the amplitude method with antennas set up at different heights;
- (d) measurement of Doppler frequencies by phase-time and sector recording methods;

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(e) measurement of the apparent geocentric velocities of meteor entry.

Measurements of all parameters cited were to be made on different azimuths within a 2π limit using a "pulsed" antenna.

Threshold signal power can be increased by increasing the radiated wavelength ($P_{th} \sim \lambda^3$), given a maximum self-excited oscillator power of $P_p \approx 45-55$ kW and a receiver response limited by antenna noise of $\alpha = 5 \cdot 10^{-14}$ W. The selection of the wavelength for the SOM-III radar therefore was taken as 10 meters (further increase in λ will result in the reflection of radio waves from ionospheric inhomogeneities). Receiver bandwidth was selected as optimum at $\Delta f \leq 1/\tau$ ($\tau \leq 10$ msec). The noise voltage was taken as $\bar{u}_n \approx (4kTR\Delta f)^{1/2}$ (when $\Delta f = 80-100$ kHz, $\bar{u}_n \approx 4$ μ V).

These factors became the basis for the selection of the following principal parameters for the optimum variant of a meteor radar: wavelength $\lambda \approx 10$ meters; pulse power $P_p = 45-55$ kW; pulse width $\tau = 10$ μ sec; repetition frequency $F_r = 50-100$ pps; receiver sensitivity $\alpha = 5 \cdot 10^{-14}$ W when $\Delta f \approx 60-100$ kHz; five-element "wave duct" antenna with gain $G = 20$.

Description of the SOM-III Block Diagram

The radar transmitter and receiver are installed in the same van. The antenna array, consisting of two in-phase fed antennas in each stage, is mounted on the van. The van can rotate as a unit in accordance with a specified program. Figure 1 is the block diagram of the SOM-III radar.

The transmitter, 7, operates in the self-excited oscillator mode with push-pull plate modulation. The radiated frequency is stabilized by quarter-wave cavity resonators connected to the tube cathodes.

The trigger, 8, ensures synchronous operation of the radar as a whole and transmitter modulator triggering as well. One of two frequencies, $F_r = 50-100$ pps, can trigger the radar. All three trigger frequencies are phased with respect to high-voltage rectifier pulsations supplied to the transmitter modulator and ensuring the stability of the amplitude of the radiated pulses.

The frequency repetition switch, 9, generates a higher pulse repetition frequency to trigger the transmitter, 7, and is cut in with the arrival of

a useful signal from the selector, 6. The pulses generated by the repetition frequency switch are mixed into the main series of trigger pulses in the synchronizer, 8. The transmitter in this case is operated in the boost mode for a short period of time. This unit is necessary to measure the apparent geocentric velocities of meteors. One additional main pulse, needed to determine the direction of the drift during sector recording, is generated when key K_1 is switched to the AMP (additional main pulse) unit, 18.

The receiver has two channels, a main, 2, and an auxiliary, 1. The auxiliary channel is used to measure the angles of arrival of a reflecting point by the amplitude comparison method at two antennas with different heights.

Signals received by the antennas are amplified in the high-frequency stages, 1 and 2, and are fed to the receiver, 5, through a switching gate, 3, assembled in a conventional circuit. An electronic key, 4, switches the switching gate. The main synchronizer, 8, synchronizes switching.

The receiver, 5, is a conventional superheterodyne circuit with dual frequency conversion and an output intermediate frequency of 2.0 MHz.

Signals flow from the receiver to the selector, 6, where signals are selected out of the noise by duration of reflected signal, amplitude of threshold level, and by the synchronism of the radar's pulsing. Selector 6 generates sensitizing pulses which are fed to the modulators of all indicators.

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Signals are fed to the amplitude indicator, 12, from receiver 5 after detection and a 3-4 μ sec delay. The linearity of the reception channel is such that the signal is stronger than the noise by a factor of 15 to 20.

A range indicator, 15, is used to record the slant range. A synchronized pulse from selector 6 is supplied to the range indicator, where it is seen as a pair of points. Sweep length corresponds to range from 100 to 500 km. Range markers, 20 km apart, are provided to measure range.

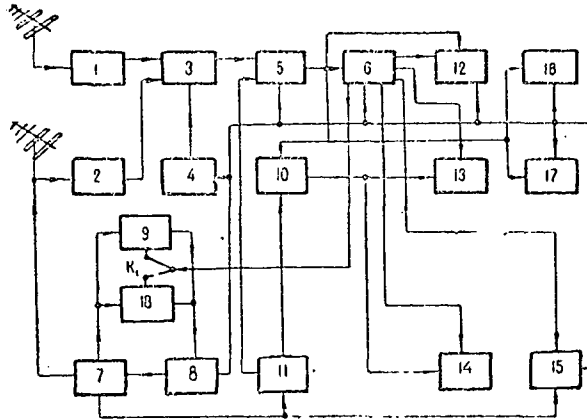


Figure 1. Block diagram of the SOM-III radar.

The oscillations of a pseudocoherent beat-frequency oscillator, generated in the phase synchronization unit, 11, are used to isolate the Doppler beat from the reflected signal frequency and the original frequency generated by the self-excited oscillator. The reference frequency is formed during phase synchronization of the oscillations of the high-frequency oscillator operating in the pulse mode and the oscillations of a special coherent beat-frequency oscillator. Phase synchronization of the pseudocoherent beat-frequency oscillator is by sync pulses from the transmitter flowing through the receiving channel at the intermediate frequency $f_i = 20$ MHz. Coherence is retained within one repetition period for intervals between transmitter pulses of 5 to 10 msec.

Phase detector 10, a symmetrical sum-difference circuit with a bridge rectifier suitable for pulse work, is used to isolate the beat voltage from the reference oscillator and the reflected echo signal. A two-channel phase detector is used to determine the trace displacement sign. A phase shifter supplies the signal to the second channel with a 90° shift in phase. The coherence of the reference oscillator and the phase shift between the two channels in the detector is monitored at the phase detector output by the echo signal from the mountains [6].

Two indicators, one a phase-time, the other a "sector display," are used to record the meteor trail drift. Use of two indicators makes it

possible to study temporal changes in the drift rate. The signal flow is from the discriminator, 10, to the phase-time indicator, 13, which records reflected echoes with duration $\tau_e > T_g$ (the Doppler period).

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The same signal flows from discriminator 10 to the "sector display" indicator, 14, which records the reflected echoes with duration τ_e shorter than the Doppler period T_g .

A reflected signal power monitor unit, 17, is used to monitor the stabilization of the operation of transmitter 7, and of the receiving channel. This is done by gating the signal from the mountains, converting it into direct current, and continuously recording this voltage on a type N-370M recorder. This reflected signal power measuring device monitors the transmitter's radiated amplitude, as well as the stability of the receiving channel.

Noise is recorded by device 16 continuously in order to study cosmic noise, which fluctuates over the 24-hour period, and permits monitoring the signal/noise ratio.

Transmitter Frequency Repetition Switch

Figure 2 is the block diagram of the frequency repetition switch for triggering the transmitter. The master repetition frequency for triggering the transmitter is 100 pps. A higher repetition frequency, 400-700 pps, is needed to determine meteor velocity from the diffraction pattern. A circuit that switches transmitter operation to a high-power mode is used because there is no way to obtain more than 40 kW from the type GI-1 tubes used in this particular transmitter when repetition frequency is increased.

Signals flow from the receiver, 1, to the selector, 2. A signal satisfying selection conditions is fed into the resolver, 3, which generates a 0.1 second pulse, during which time high-frequency repetition pulses are supplied to the synchronizer from the increased repetition frequency unit, 4, which operates continuously, to trigger the modulator in the transmitter, 5.

Use of an increased repetition frequency causes a drop in pulse power, but as the experiment showed, when operation is in the boost mode with $t = 0.1$ second, the power drop is slight.

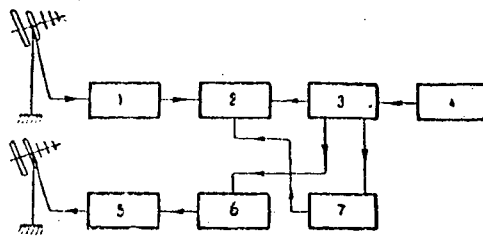


Figure 2. Block diagram of the repetition frequency switch for triggering the transmitter.

Time relay 7 is triggered when the increased frequency unit is cut in, opening the signal circuit from selector 2. Relay operating time can be adjusted from 0.5 second to several tens of seconds. This was incorporated to preclude repeat sounding of the same trail.

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The following expression can be used to find the meteor velocity from its diffraction pattern

$$V_g = \frac{t}{2} F_r \frac{\sqrt{R\lambda}}{N}, \quad (1)$$

where

V_g is the apparent meteor velocity;

t is the time interval between the diffraction echo maximum and minimum;

N is the number of pulses between maximum and minimum;

F_r is the radar's repetition frequency.

The mean probable velocity of meteors is 40 km/sec, so the repetition frequency, F_r , should be at least 500 pps.

Angle Measurement Device

The angle measurement device is used to determine the altitudes of the reflecting points on a meteor trail. One of the simplest of the methods used to determine the bearing of a target, the amplitude method, which uses the directional properties of antennas, can be used to measure

the angles of arrival of a reflected signal. Target direction finding is by the comparison of two amplitudes. The signal voltages at antennas h_1 and h_2 can be represented in the form

$$\begin{aligned} U_{h_1} &= U_0 f_1(\alpha), \\ U_{h_2} &= U_0 f_2(\alpha), \end{aligned} \quad (2)$$

where

$f_1(\alpha)$ and $f_2(\alpha)$ are the direction-finding characteristics of the antennas.

The ratio of the amplitudes of two incoming signals, U_{h_1} and U_{h_2} , are proportional

$$\frac{U_{h_1}}{U_{h_2}} = \frac{f_1(\alpha)}{f_2(\alpha)}. \quad (3)$$

The azimuth, α , to the reflecting target [7], can be determined on the indicator by measuring the reflected signal amplitude from two antennas.

Antenna heights are $h_1 = \lambda/2$ and $h_2 = 3/4 \lambda$. The radiated power maximum occurs at $\Theta = 30^\circ$ and $\Theta = 49^\circ$.

The signals from the antennas are amplified in two high-frequency stages, 1 and 2, and are fed into the main receivers, 5, through electronic switch 3, controlled by key 4, passing the antenna pulses according to the clock time, and then on into the recorder (see Figure 1).

Sector Recording of Doppler Frequencies

Use of sector recording increases the number of meteor echoes processed [4, 8]. When the phase-time method is used, 25 to 30 percent of the radio echoes are not processed because the radio echo reflection time is less than the Doppler period, because of underdense trails. Combining the phase-time and "sector display" recording methods makes it possible to process 80 percent of all radio echoes received. It is difficult to determine the direction in which the meteor trail is drifting because of the low frequency of the radar's transmissions when sector recording is used. In our case, we determined the direction of drift by using an additional main pulse, an AMP.

A sync pulse is supplied to the AMP unit, 18, from the transmitter, 7. The AMP unit forms a pulse for additionally triggering the transmitter modulator, the TTM pulse, which is mixed with the main series of sync pulses in unit 8. TTM pulse passage is enabled in the selector, 6, as a result of the signal reflected from the meteor. After pulse passage is enabled, the TTM pulse is fed into the master oscillator, 8, mixed with the main series of pulses, and fed into the transmitter modulator forming the AMP (see Figure 1).

The AMP appears on the right, or left, of the transmitter's main pulse, depending on direction of meteor trail drift. The AMP circuit is reviewed in more detail in reference [8].

Cosmic Noise, Receiver Response, and Transmitter Power Measuring Device

Figure 3 is a block diagram of the noise and reflected signal power measuring device. The gating stage, 1, is triggered by a pulse from the transmitter modulator and is used to separate signals with different ranges.

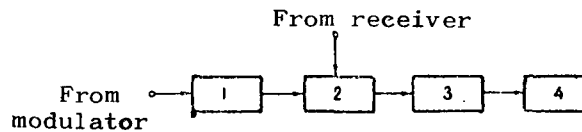


Figure 3. Block diagram of the noise and power monitor measuring device.

Displacing the gate, we can record (a) the amplitude of the main pulse controlling transmitter power, (b) the amplitude of pulses reflected from the mountains and controlling transmitter power and the response of the receiving channel simultaneously, and (c) we can measure cosmic noise. Receiver signals flow into amplifier 2, where high-frequency amplification takes place, the signals are detected, video frequency amplification takes place, and the signals then are fed into converter 3 which converts the pulse voltage into direct current voltage. The direct current voltage magnitude depends linearly on the magnitude of the pulse voltage. The direct current voltage is amplified and fed into the type N-370M recorder, 4.

The measuring device thus can monitor the receiver response and transmitter power, and can measure cosmic noise in accordance with a specified program. The results obtained from recording noise and reflected signal power can be used to make more precise corrections to the data on the daily density of the radiant points, and to study the amplitude characteristics of meteor echoes.

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